Pollutant Transport Analyses

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Introduction

- The impact of pollutant transport on the ozone air quality in a downwind airshed is a function of the precursor emissions in the upwind airshed, the losses of pollutants by deposition and reaction along the transport path, the formation of ozone along the transport path, the meteorological situation which transports and mixes the pollutants, and the local precursor emissions in the downwind basin.
- Depending upon the particular scenario, effective control strategies may require emission controls in the upwind airshed, the downwind airshed, or both. Grid modeling may ultimately be needed in many situations to evaluate the relative effects of different control strategies. Issues to be considered in transport analyses include:
  - Transport of both ozone and ozone precursors
  - Biogenic emissions along a transport path
  - Duration and temporal variability, e.g., same-day transport, overnight transport, and transported pollutants that remain overnight in the receptor area (carry-over)
  - Upper-air meteorological data are critical and upper-air air quality data are desirable.

Pollutant Transport Issues (1 of 2)

The following issues should be considered when assessing pollutant transport:

- Definition of boundaries (and scale): over which boundary are we assessing transport?
- Pollutants: Ozone <u>and</u> precursors.
- Continuing reaction to form ozone: photochemistry is occurring during transport.
- Transport versus carryover (recirculation): are pollutants transported into the area of interest; are ozone and precursors from the area carried over from day to day; or is the area experiencing a combination?
- Aloft and surface air quality and winds: what data are available and where are the sites located? Are special studies data available?
- Transport time: How long does it take for air parcels from upwind sources take to reach the receptor?

Pollutant Transport Issues (2 of 2)

The following issues should be considered when assessing pollutant transport (concluded):

- Characteristics along transport path: Are important ozone precursor emission sources situated along the transport path?
- Where do ozone and precursors transported into an area originate? What route do they take?
- When do ozone and precursors arrive in the area?
- How frequently does transport occur?
- How much of the high ozone concentrations can be attributed to transport?
- How does the analyst compare transported ozone and precursors with locally generated ozone and precursors?

Approaches to Quantifying Transport (1 of 6)

PAMS and supporting data can be used to perform the following analyses (*useful data, at a minimum*):

- Geographical extent of high ozone concentrations, extent of exceedances and similarity of ozone peak concentrations: Do high ozone concentrations extend throughout the upwind and downwind air airsheds? Does evidence from other methods, such as timing of the peak ozone concentrations also support transport? (*PAMS and NAMS/SLAMS ozone*)

- Timing of peak ozone concentrations along a potential transport path: analyses of the time of peak ozone concentration at various monitoring sites can yield useful information on transport patterns and source areas. A consistent transport pattern exists if the ozone peaks occur later at each successive downwind site, and if the time between peak concentrations is consistent with the measured wind speeds. This technique only works when transport occurs at the surface, rather than aloft. (*PAMS and NAMS/SLAMS ozone*)

Approaches to Quantifying Transport (2 of 6)

PAMS and supporting data can be used to perform the following analyses (*useful data, at a minimum*) (continued):

- Age of air mass (using hydrocarbon ratios): Do VOCs at the downwind sites show evidence of aging? (*PAMS VOCs*)
- Age of air mass (using indicator criteria): Do other pollutant ratios or concentrations show evidence of aging? (*PAMS ozone, special studies data*)
- Relative emissions in the upwind and downwind areas: ratio of precursor emissions in the upwind airshed to those in the downwind airshed; ratio of upwind to downwind emissions, with emissions accumulated along a typical trajectory path upwind and downwind of a division between the air basins; and a ratio of upwind to downwind emissions using meteorological and photochemical models. (*Emission inventory*)
- Presence or absence of a low-level jet: Does a low-level jet occur on nights prior to ozone exceedances? Do high levels of ozone and/or precursors exist in the jet? (*PAMS upper-air meteorology, special studies data*)

Approaches to Quantifying Transport (3 of 6)

PAMS and supporting data can be used to perform the following analyses (*useful data, at a minimum*) (continued):

- Surface wind run: are surface wind speeds between major upwind source areas and the downwind source receptor site consistent with the potential transport distance and with the time of the peak ozone concentration? The winds might be high enough to indicate a polluted air parcel could have traveled the distance between the source and receptor. In addition, the travel time (estimated from the surface wind speed) might match the time between the morning rush hour and the time of the ozone peak (if same-day transport). Both same-day and previous-day winds might need to be considered. (*PAMS and other meteorology*)
- Aloft wind speed and direction: as with the surface winds, are the direction and speed consistent with transport? (*PAMS upper-air meteorology*)

Approaches to Quantifying Transport (4 of 6)

PAMS and supporting data can be used to perform the following analyses (*useful data*, *at a minimum*) (continued):

- Air-parcel trajectories: air-parcel trajectories estimate the path of a hypothetical air parcel over a selected period of time. Back trajectories follow an air parcel to illustrate where the air might have come from; forward trajectories follow an air parcel on the way from a source region to illustrate where an air parcel might go. Do forward and back trajectories support transport? (*PAMS surface and upper-air meteorology*)
- Surface pressure gradients: are pressure gradients between air basins consistent with transport between them? And with the trajectory results? (*National Weather Service data*)
- Depth of surface layer: was the surface layer shallow enough to keep pollutants poorly dispersed, but deep enough to allow penetration of the pollutants up valleys or over passes? (*PAMS upper-air meteorology*)

Approaches to Quantifying Transport (5 of 6)

PAMS and supporting data can be used to perform the following analyses (*useful data*, *at a minimum*) (continued):

- Isentropic analysis: Do isentropes support other transport analyses? (*PAMS upper-air meteorology*)
- Ventilation and recirculation analysis: Do upper-air transport distances, wind directions, and recirculation factors support transport? (*PAMS upper-air meteorology*)
- Boundary measurements: What are ozone or precursor concentrations at the upwind boundaries of the area of interest? How do these concentrations compare to the downwind concentrations? (*PAMS VOCs*, *NO_x, and ozone; special studies data*)
- Flux estimates (e.g., mass/time): What are the ozone and precursor mass/time rates through selected boundaries? (*PAMS upper-air meteorology, special studies data*)

Approaches to Quantifying Transport (6 of 6)

PAMS and supporting data can be used to perform the following analyses (*useful data, at a minimum*) (concluded):

- Tracers: Are there unique tracers (i.e., unique species or ratios) for the upwind emissions sources? When and how much of these tracers arrive at the receptor? *(PAMS VOCs, special studies)*
- Grid Modeling: How do grid modeling results compare to observations? *(Model output, PAMS air quality and meteorology)*

Case Studies

- A case study is the in-depth analysis of the meteorology and air quality experienced during a selected high ozone concentration episode. A case study links individual analyses into a coherent picture.

Analysis Objectives

- To integrate the meteorology and air quality and develop a conceptual model of the important meteorological factors and air quality which help to produce high ozone concentrations in a region.

Constructing a Case Study (1 of 2)

- Select an episode(s). Base the selection on the occurrence of high ozone concentrations and the availability of meteorological and air quality data (including upper-air meteorological measurements).
- Understand the emissions sources that could impact the receptor sites.
- Assess air quality conditions including the extent and timing of peak ozone concentrations and assessing the background ozone concentrations.
- Assess the meteorological conditions including the synoptic pattern and prevailing surface conditions.

Constructing a Case Study (2 of 2)

- Assess the origin of pollutants by coupling the meteorology and the patterns of ozone and precursor concentrations.
- Assess transport of ozone and precursors beginning with the morning conditions and proceeding throughout the episode.
- Perform isentropic analyses and analysis of air quality data collected by aircraft and by surface monitoring sites to understand how ozone and ozone precursors are horizontally and vertically transported.

Example Case Study

Transport into and within the Lake Michigan Air Quality Region on July 18, 1991. Episode selection was based on the following:

- July 18 had the highest ozone concentrations of the episode.
- Nine sites within the region experienced ozone concentrations over 125 ppb.
- Speciated hydrocarbon data were available.
- Upper-air meteorological data were available.
- Aloft air quality data were available.
- Boundary air quality data were available.

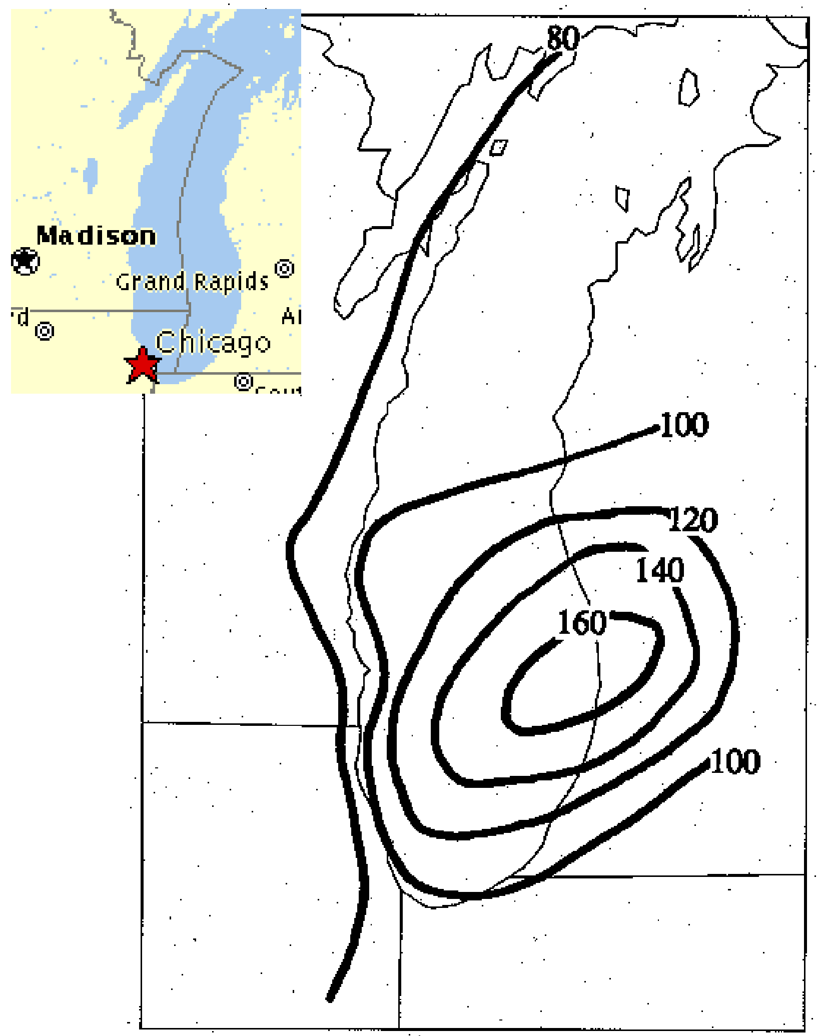
This case study has been augmented with analysis examples from other parts of the U.S. to illustrate data analysis techniques applicable to PAMS and PAMS-like data.

Other Tasks for Case Study Analyses

- Perform case studies of several ozone episodes.
- Compare episode characteristics and the conceptual model with past year episodes.
- Make recommendations for future modeling efforts such as:
  - Selection of episodes to model and why these episodes are important.
  - Selection of data which should be used for boundary and initial conditions.
  - Selection of data which should be used for data assimilation.
  - Selection of data which should be used for model evaluation.
  - Examples of meteorological and air quality phenomenon which should be represented in the models (for model development and evaluation).

Ozone Concentration Contours

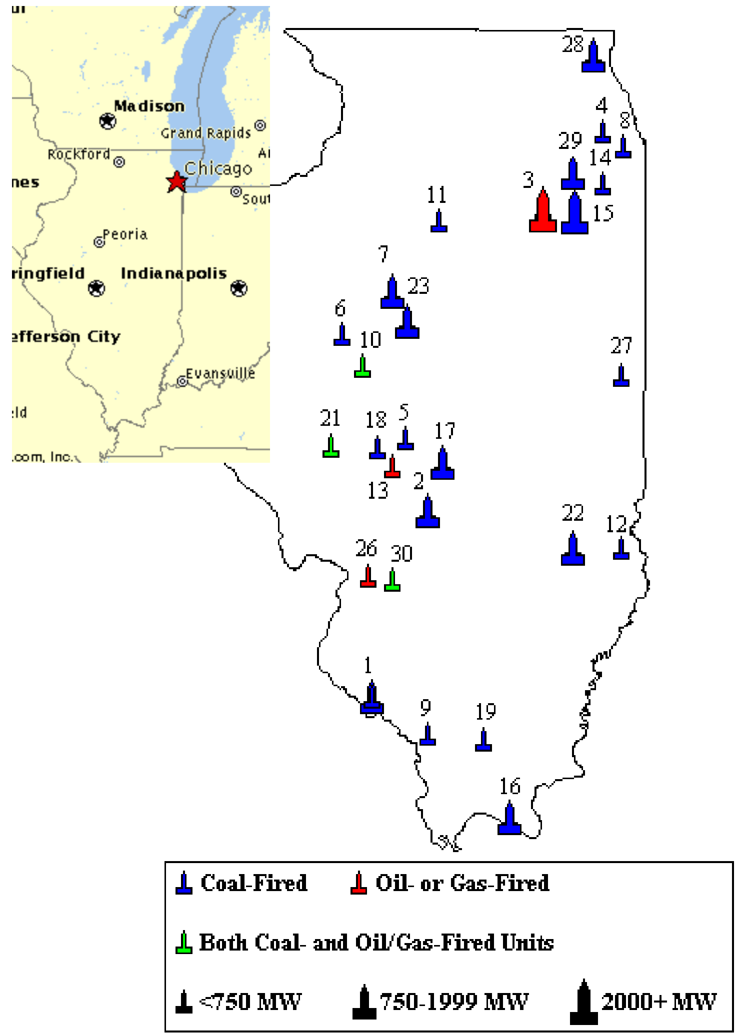
- Contour of maximum ozone concentrations (ppb) on July 18, 1991 in the Lake Michigan region (Dye et al., 1995).
- The ozone contours need to be assessed with respect to the meteorology observed that day, background ozone concentrations, and the upwind emissions. These plots are shown later in this section.



Prepared using NCAR graphics and contoured by hand.

Understanding Emission Sources

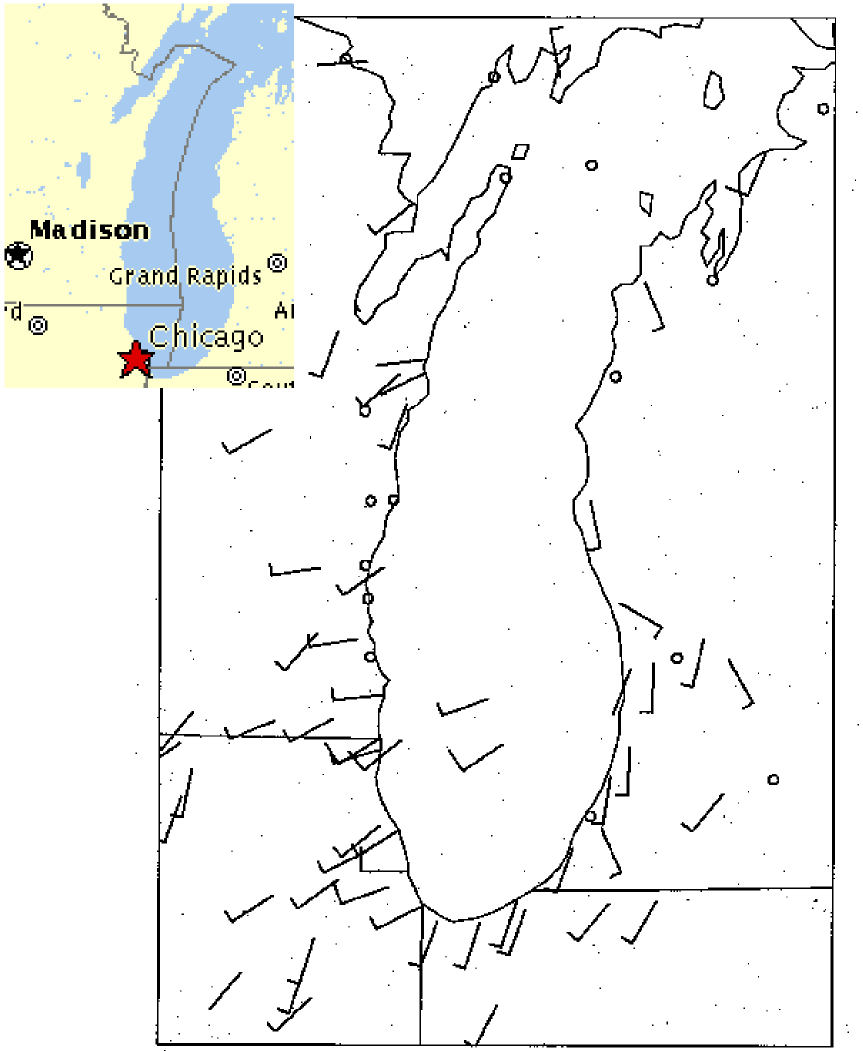
- It is important to understand the emission sources in your area of interest. Useful plots include total VOC and NO_x emissions by county, by source type (e.g., mobile or stationary sources), or emissions prepared for a grid model (gridded emissions).
- This example shows Illinois power plant sizes (in MW) for an unspecified year. NO_x emissions for each plant are available on the website.



From *http://www.epa.gov/acidrain/emission/il/index1.htm*. Numbers refer to a list of facility names available on the website.

Meteorological Conditions (1 of 5)

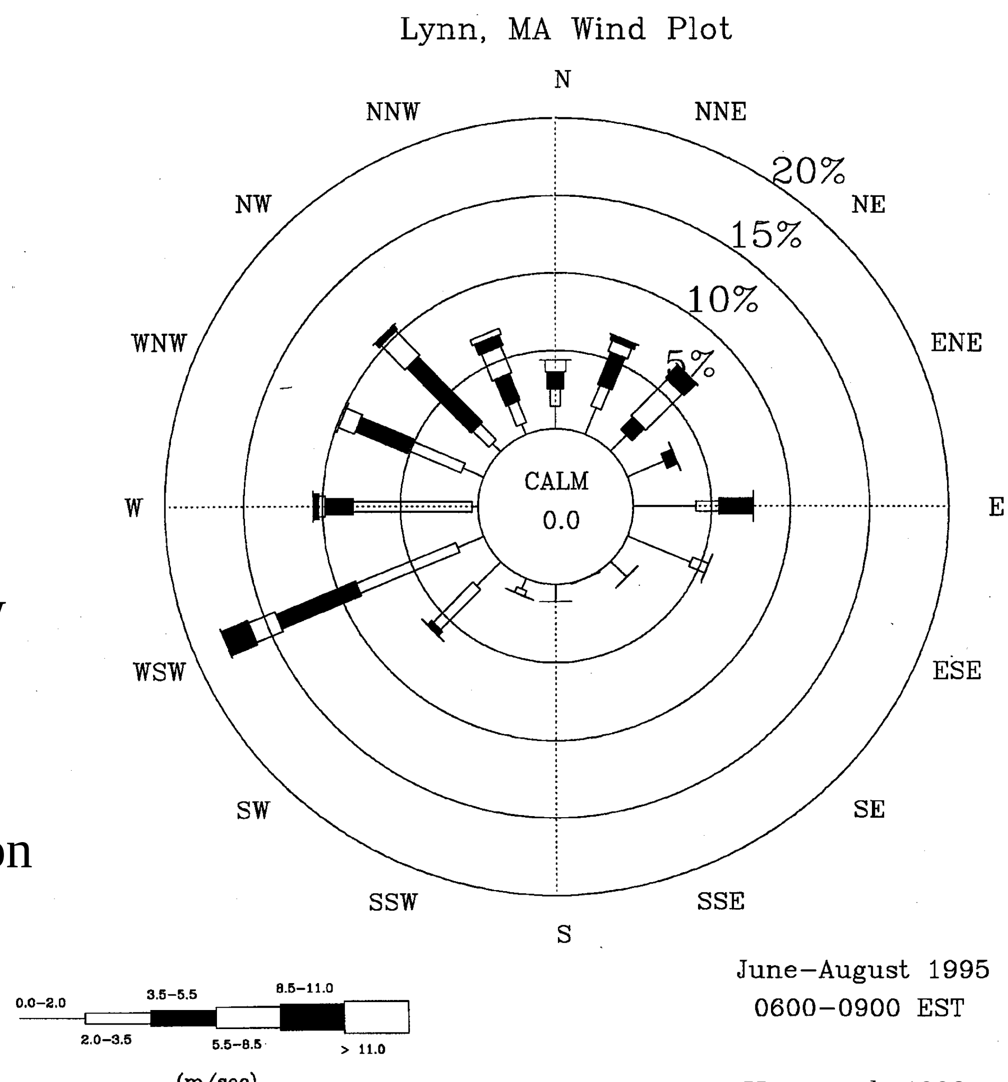
- Surface winds on July 18, 1991 at 0600 CST in the Lake Michigan region (Dye et al., 1995).
- This plot shows that in the morning, surface winds could carry pollutants across the lake from the Chicago area. Trajectory analyses could help the analyst better visualize the transport path and timing.



Prepared using NCAR graphics. Winds from many sites are omitted for clarity.

Meteorological Conditions (2 of 5)

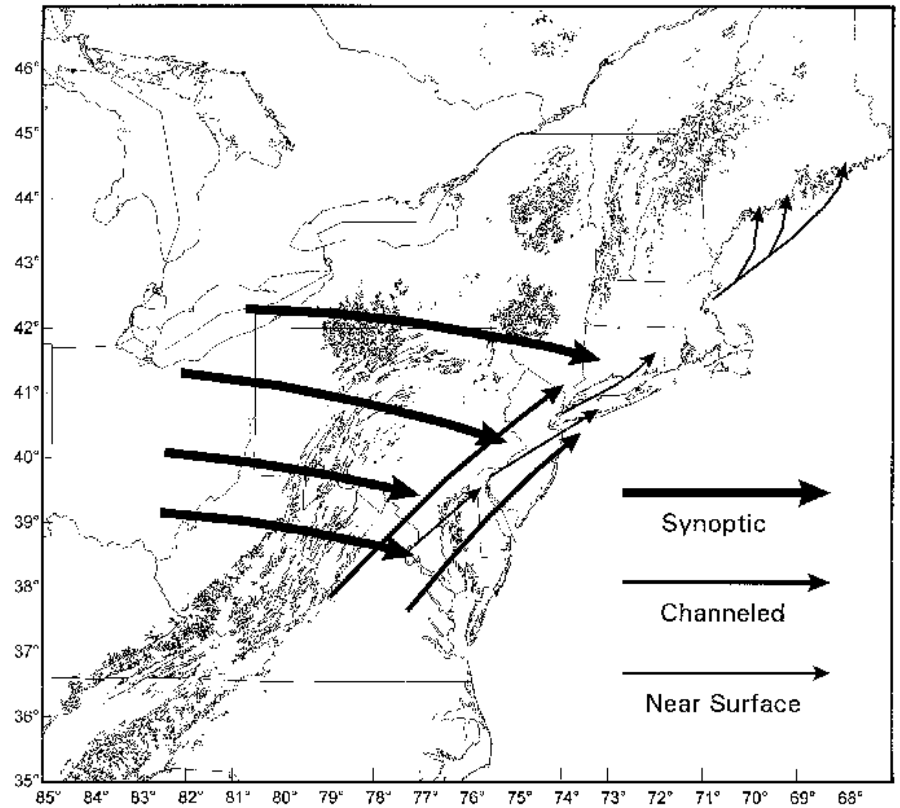
- Another way to investigate meteorology at a particular site is to use a wind rose plot.This example shows a wind rose for data collected at the Lynn, MA PAMS site from June through August 1995 at 0600 to 0900 EST.
- This plot shows winds were most frequently from the WSW at this time of day. Wind rose plots for other time periods, including 24-hr, should also be explored. In addition, “pollution rose” plots should be prepared. These plots depict the relationship between pollutant concentration and wind direction.



Haste et al., 1998

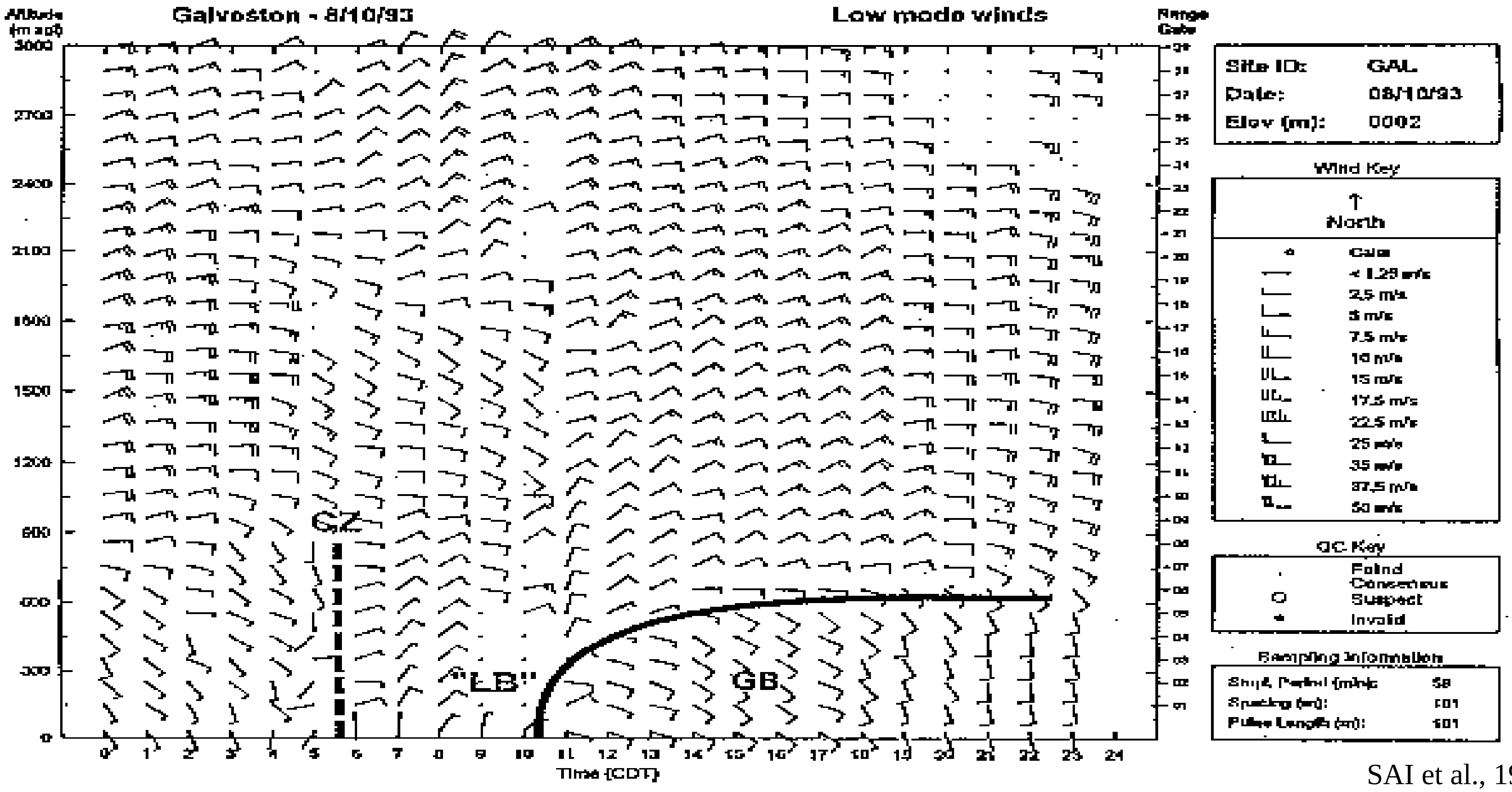
Meteorological Conditions (3 of 5)

- Regional meteorological conditions should be explored as well.
- This plot shows the different transport regimes observed during the 1995 ozone episodes in the Northeast corridor:
  - Synoptic flow (about 800 to 2000 m msl)
  - Channeled flow (about 200 to 800 m msl)
  - Near-surface flow (0 to about 200 m msl)



Blumenthal et al., 1997

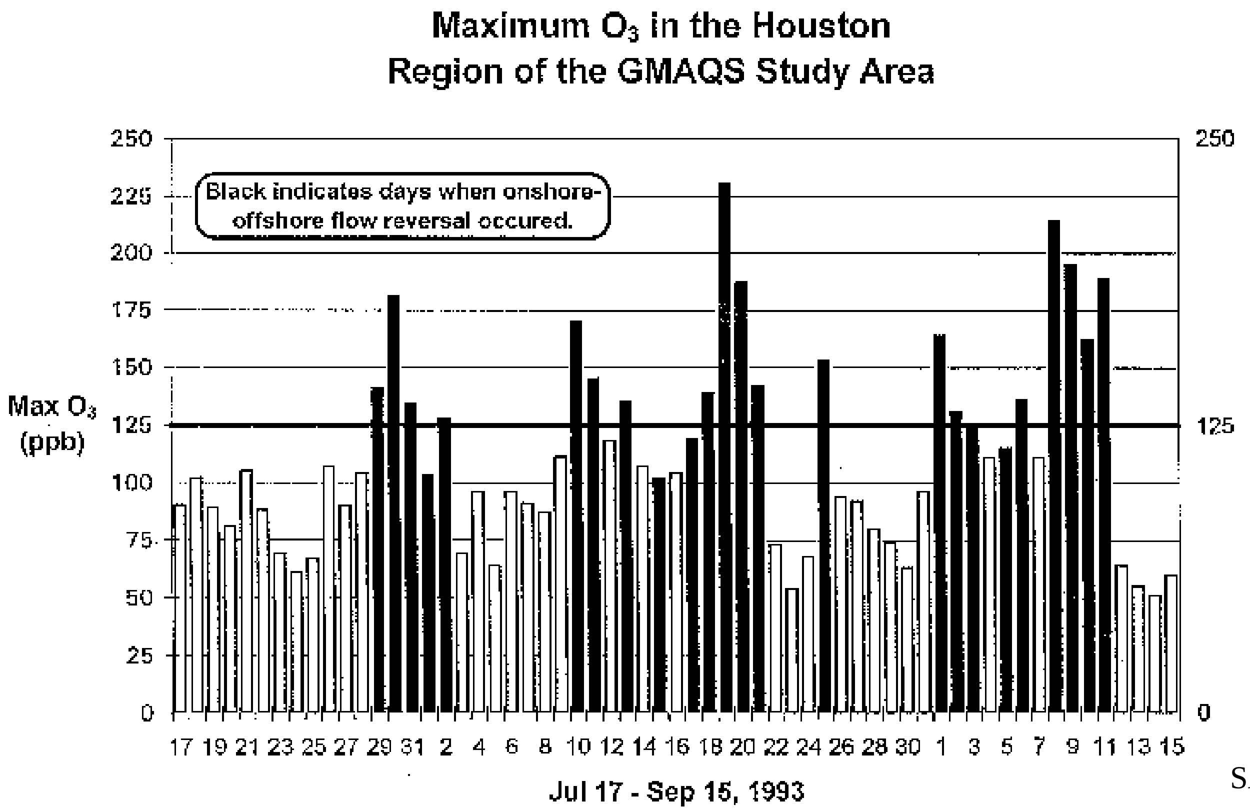
Meteorological Conditions (4 of 5)



SAI et al., 1995

Meteorological features important to ozone transport need to be explored. This example shows wind profiles measured by the 915 MHz radar profiler at Galveston, TX on August 10, 1993. Solid lines indicate the sea breeze (SB) and land breeze (LB); the dashed line indicates a convergence zone (CZ) that formed at the onset of the land breeze. The first level of winds was measured by the surface station that was collocated with the profiler.

Meteorological Conditions (5 of 5)

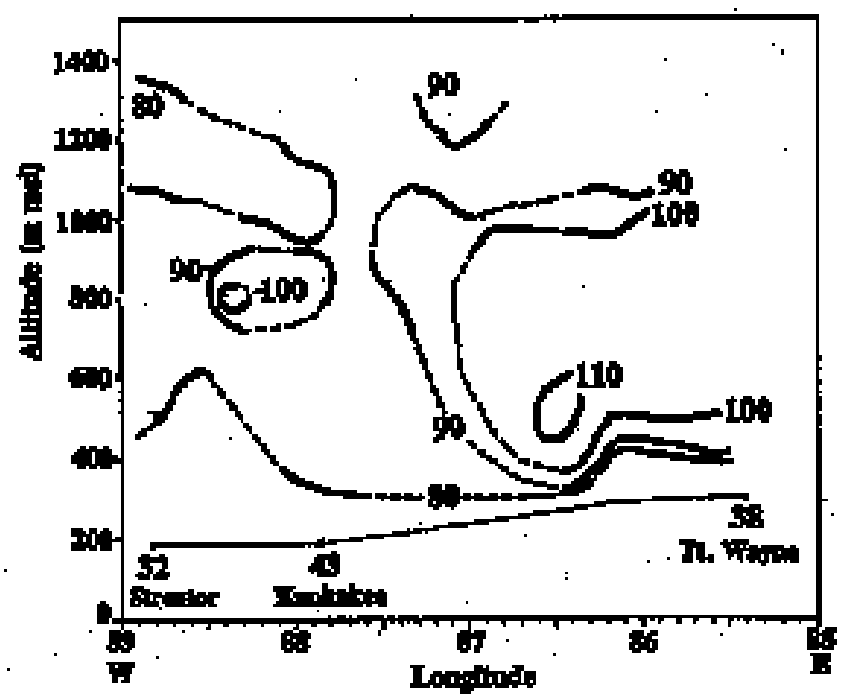


SAI et al., 1995

- In areas with a frequently occurring nocturnal jet, sea/land breeze recirculation, or other major meteorological feature, the relationship between ozone concentrations and the presence or absence of the feature should be explored.
- This example shows maximum concentrations observed in southeast Texas during the GMAQS project; the black bars indicate days on which a sea/land breeze circulation formed that produced an onshore-offshore flow reversal in the region. One most of these days, ozone concentrations were high.

Assess Boundary Conditions

- What were the boundary conditions both aloft and at the surface of the region of study?
- This example shows surface and aloft ozone concentrations along the 1991 Lake Michigan Ozone Study southern boundary during the morning on July 18.
- Aloft ozone concentrations were typically between 70 and 110 ppb at all times of day; these concentrations are well above typical clean air ozone levels of about 40 ppb in the summer.



Ozone concentrations are hand contoured.
Roberts et al., 1994

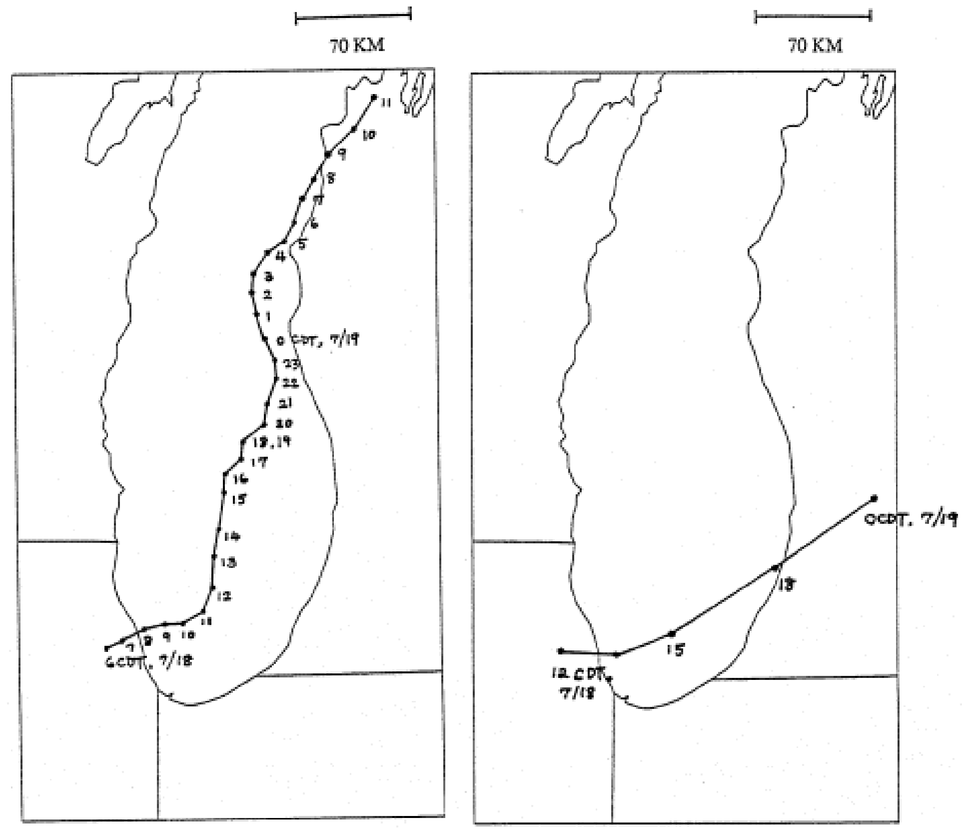
Inspect Trajectories (1 of 2)

In preparing trajectories, consider the following:

- Trajectories can be computed for many hours backward or forward in time. For back trajectories, it may be most useful to focus on the several hours (depending upon wind speed) prior to the peak ozone concentration. For forward trajectories, one may focus on starting with the time of peak emissions. The farther the trajectories are from the wind measurements, the more potential there is for error. With hilly or coastal terrain, there is even greater potential for error.
- The back trajectories provide an estimate of the general direction from which air parcels traveled prior to the time of the daily peak ozone concentration.
- Trajectories should be used in a qualitative way to assess a likely path for the air parcels; they do not represent an exact pathway. One way to visualize this is to picture the trajectory as a wide ribbon rather than as a narrow line.

Inspect Trajectories (2 of 2)

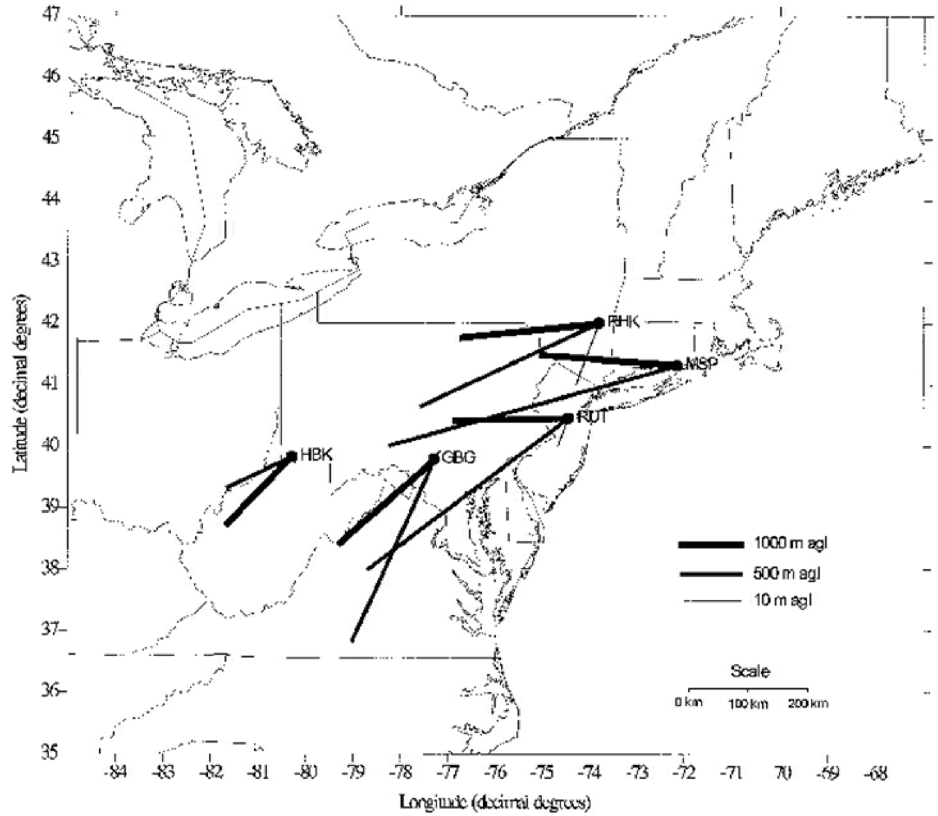
- For the Lake Michigan case study, forward trajectories were computed for winds at the surface and winds aloft beginning in the morning and afternoon, respectively.
- The trajectories show winds could carry pollutants across the lake. These analyses support the observations made using the emissions, meteorological conditions, and ozone contour plots.



Forward trajectories calculated using surface winds at 0600 CDT and 300 m agl winds at 1200 CDT starting at Schiller Park, IL on July 18, 1991 (Tremback and Lyons, 1993).

Wind Runs

- Another analysis used to illustrate the differences between surface and aloft transport is the computation of wind runs.
- This example shows twelve-hr resultant wind vectors for radar profiler sites in the northeastern U.S. from 1900 EST on July 31 through 0700 EST on August 1, 1995. These wind runs were constructed to investigate overnight transport.
- This example illustrates the potentially wide variation in wind speed and direction at different altitudes.

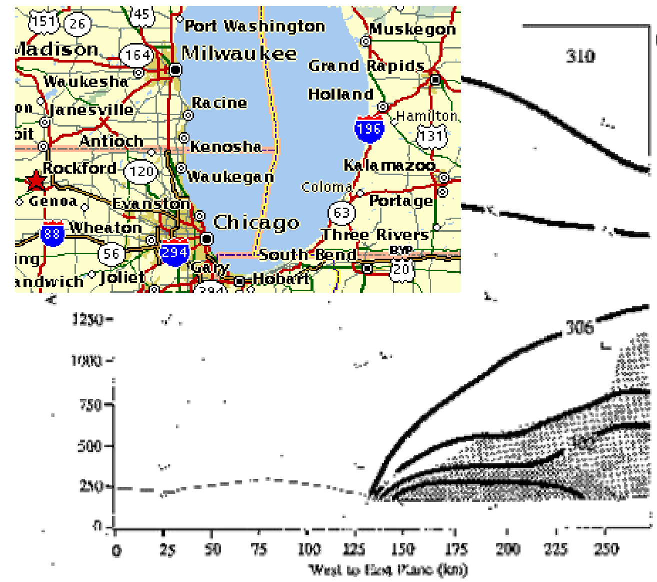


Vectors are based only on data from the end points. The wind runs computed for the 10 m agl levels at Gettysburg and Holbrook, PA were less than 20 km and thus to not show on this map.
Ray et al., 1997

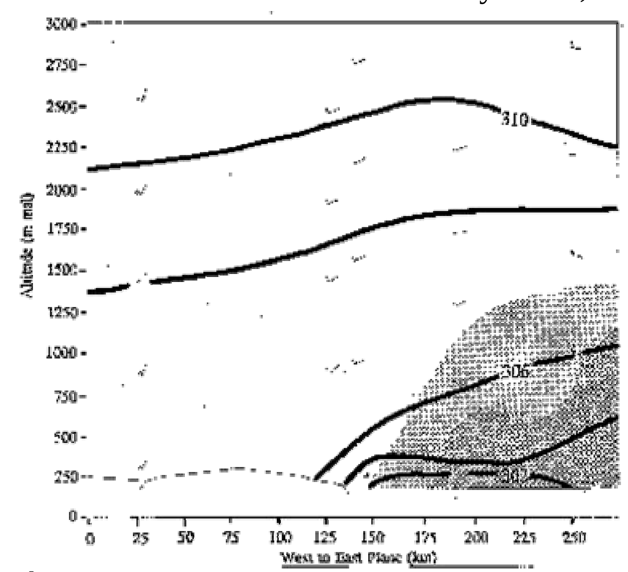
Isentropic Analysis

- The analyst is seeking consensus among the data analysis results. Another approach to transport analysis using upper air meteorological data is to perform isentropic analyses. This example shows a west-to-east isentropic cross section from Rockford, IL to Muskegon, MI on July 18, 1991 at 1500 CDT (top) and 1800 CDT (bottom).

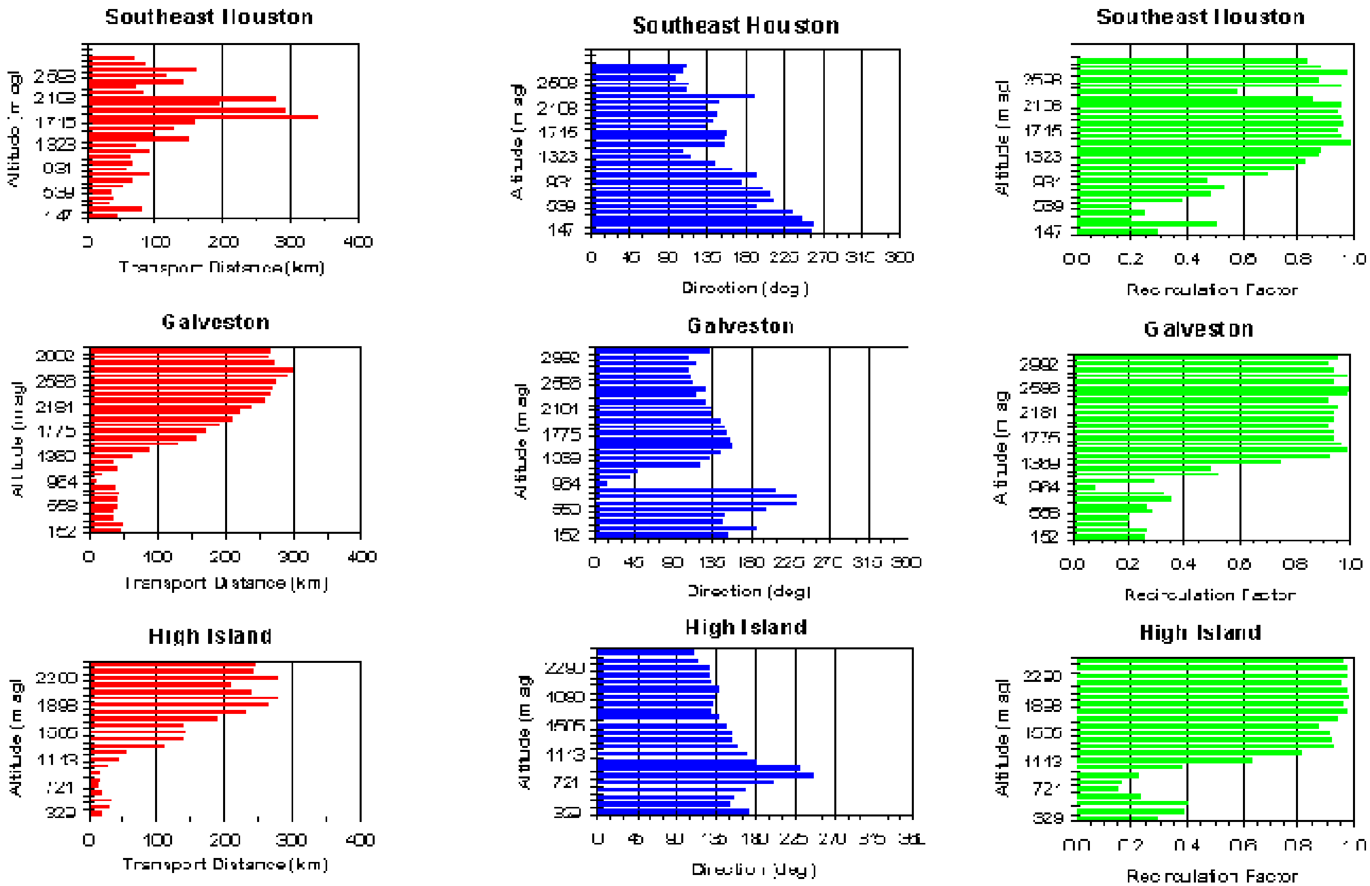
- Isentropes are contoured every 2°K. Aloft winds are plotted every 500 m at each rawinsonde site. Shaded regions denote aircraft measurements of ozone concentrations greater than 100 (light gray) and 120 (dark gray) ppb.



Dye et al., 1995



Ventilation Analysis



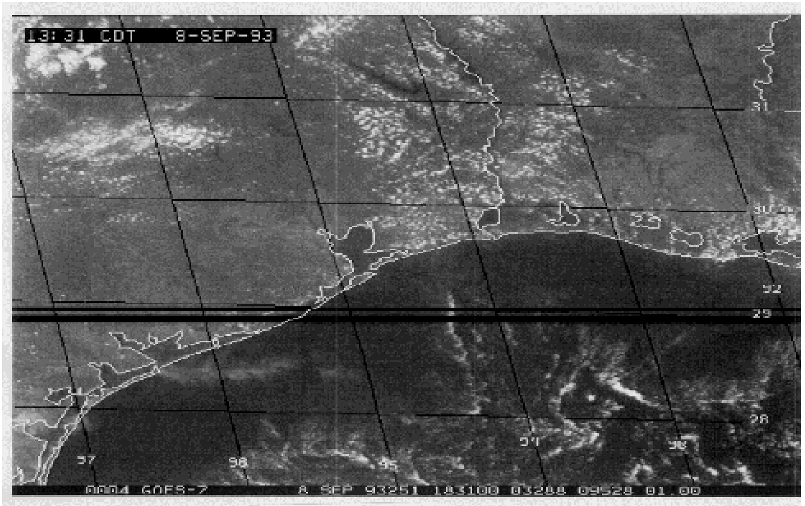
SAI et al., 1995

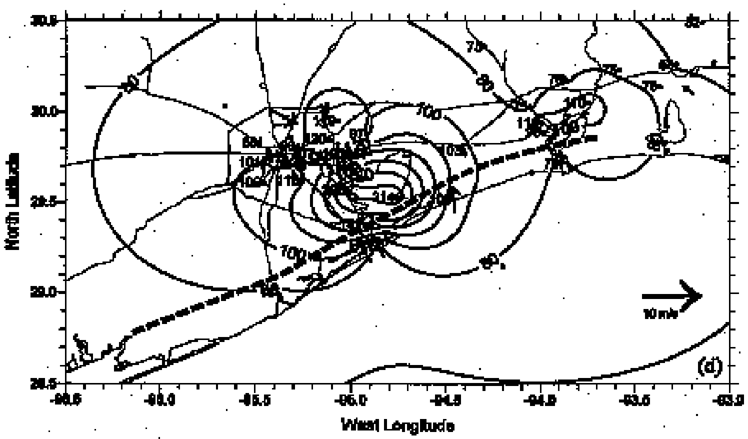
When recirculation and carry-over of pollutants may be a consideration, ventilation analysis using upper-air meteorological data is useful. This example shows vector integrated transport distances, resultant wind directions, and recirculation factors (R) calculated from data collected at Southeast Houston, Galveston, and High Island Platform (in the Gulf) radar profilers for the period 0600 to 1700 CDT on August 19, 1993. In the surface layer, short transport distances and low recirculation factors indicate stagnation of the air mass.

Investigate Other Available Data

Visible and infrared images from satellites can be used to understand weather phenomena that affect air quality conditions. These weather events include:

- Land/sea breeze circulation (in this example, note the line of clouds just inland along the coastline in the center of the image. This cloud line is the sea breeze front shown as a dashed line on the bottom figure.
- Thunderstorms, squall lines, rain, etc.
- General cloud cover (clear/cumulus/overcast).
- Synoptic weather features (cold fronts, warm fronts, high pressure systems).

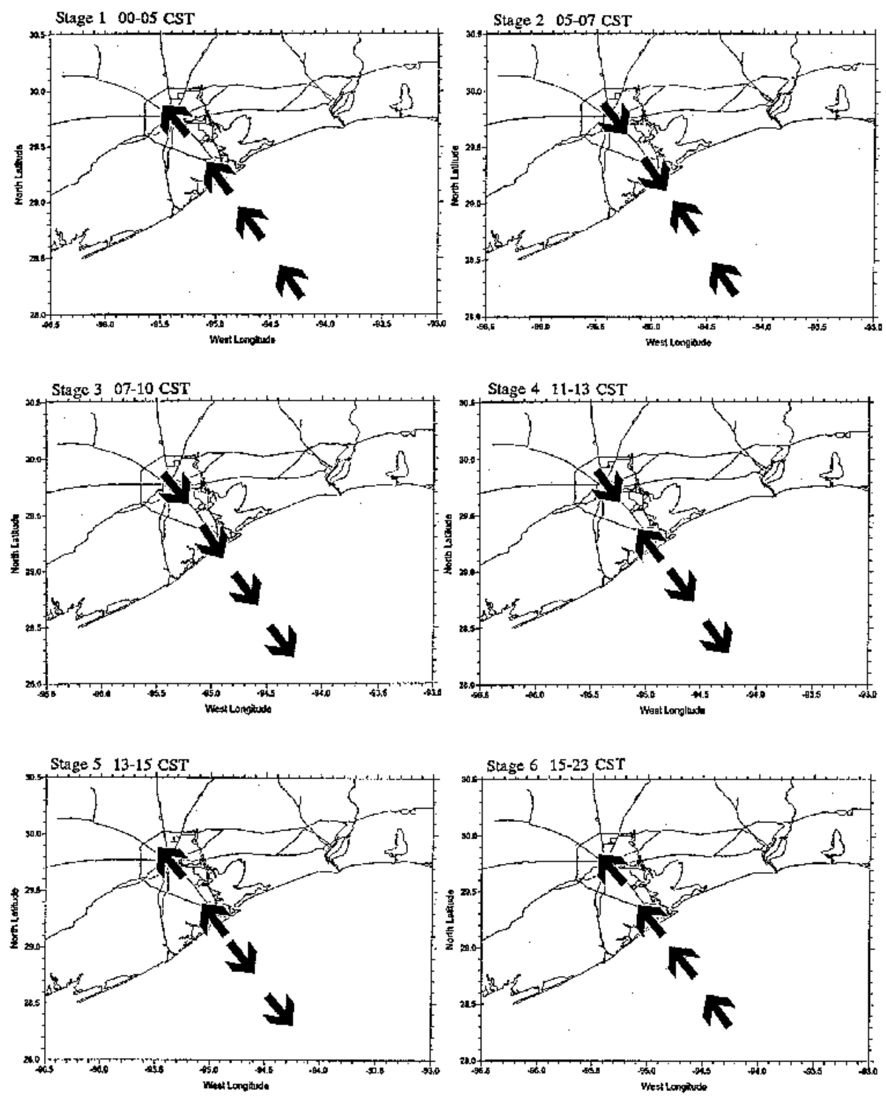




The satellite image at top was used to aid in analyses for the Gulf of Mexico Air Quality Study. The bottom contour plot was made using Surfer software (SAI et al., 1995)

Conceptual Model

- A conceptual model is a description of the important phenomena and characteristics that produce episodes of high ozone concentration.
- A conceptual model allows the analyst to summarize the current understanding of ozone episodes in a region, provides a basis for testing and evaluating specific hypotheses, and provides a basis for evaluation meteorological and photochemical models and model results.
- This example shows a conceptual model of the six stages of the onshore-offshore-onshore flow reversal in southeast Texas on episod days.



SAI et al., 1995

Methods for Estimating Relative Emission Contributions

- Ratio of precursor emissions in upwind air basin to those in downwind air basin
- Ratio of precursor emissions in a portion of the upwind air basin (that portion most connected by geography and wind patterns to the downwind area) to those in the downwind area
- Ratio of upwind to downwind emissions, with emissions accumulated along a typical trajectory path
- Ratio of upwind to downwind emissions using meteorological and photochemical models

Available Tools and Methods (1 of 3)

PAMS and Non-PAMS Upper-Air Data:

- NOAA profiler network (*http://oak.fsl.noaa.gov/index.html*)
- Special studies such as NARSTO studies in the Northeast, Texas, and California (*http://narsto.owt.com/Narsto/*); Southern Oxidant Study (*http://www.epa.gov/amdweb95/sosda.html*)
- Ozone Lidar (*e.g., http://www2.etl.noaa.gov/uv_dial.html#param*)

Trajectory Methods:

- HYSPLIT (*http://www.arl.noaa.gov/ready.html*)

Available Methods and Tools (2 of 3)

Surface air quality and meteorological data:

- AIRS Data via public web at *http://www.epa.gov/airsdata*
- AIRS Air Quality System (AQS) via registered users register with EPA/NCC (703-487-4630)
- Meteorological parameters from National Weather Service (NWS) at *http://www.nws.noaa.gov*
- Meteorological parameters from PAMS/AIRS AQS register with EPA/NCC (703-487-4630)
- Private meteorological agencies (e.g., forestry service, agricultural monitoring, industrial facilities)

Available Methods and Tools (3 of 3)

Available statistical and mapping software includes:

- AIRS graphics (e.g., *http://www.epa.gov/airsweb/maps.htm*)
- ArcInfo and ArcView (*http://www.esri.com/*)
- MapInfo (*http://www.mapinfo.com/*)
- SAS (*http://www.sas.com/*)
  SYSTAT (*http://www.spssscience.com/systat*)
  SPLUS (*http://www.splus.mathsoft.com/*)
- Surfer (*http://www.goldensoftware.com/*)
- Other similar statistical and GIS-based software

Summary

- The transport of both ozone and ozone precursors into an airshed can influence ozone concentrations and thus the selection of effective control strategies.
- Analyses using PAMS data can provide characteristics and evidence of pollutant transport in some cases; however, grid modeling may ultimately be needed in many situations to evaluate the relative effects of different control strategies in a situation with transport.
- A range of data analysis approaches using PAMS data can be applied to address transport issues, including assessing conditions at the upwind boundary; performing meteorological analyses using trajectories, wind runs, and ventilation estimates; and estimating relative emissions. Consensus among analysis results will increase the confidence of those results.
- Tools and examples analyses exist to assist in performing transport assessments.

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